

The October–November, 2003 Solar Activity and its Relationship to the “ ~ 155 day” Solar Periodicity

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Periodicities of ~ 155 days in various solar and interplanetary phenomena were first discovered during solar cycle 21 and have been shown to be intermittently present in other solar cycles. In the current solar cycle (23), they have been reported in solar energetic particle events and interplanetary coronal mass ejections. We assess whether the “unexpected” October – November 2003 burst of solar activity during the late declining phase of the cycle may have been a manifestation of such a periodic behavior, and hence might have been to some extent “predictable”. If the pattern were to continue, episodes of enhanced activity might be expected around April – May and October, 2004. There was a modest increase activity increase in mid-April, 2004 which may conform to this pattern.

1. Introduction

During solar cycle 21, a periodicity of ~ 155 days was first recognized in the occurrence of gamma ray flares [Rieger *et al.*, 1984] and subsequently identified in other solar and interplanetary phenomena. These include other flare data sets [Bai and Sturrock, 1993, and references therein; Antalova, 1994], active region parameters [Lean and Brueckner, 1989] including sunspot areas [Lean, 1990], the soft X-ray background [Aschwanden, 1994], solar proton events [Bai and Cliver, 1990; Cane *et al.*, 1998], the interplanetary magnetic field [Cane *et al.*, 1998], and the geomagnetic A_p index [Gonzalez *et al.*, 1993]. However the ~ 155 -day periodicity only appears intermittently. For example, Kile and Cliver [1991] found it was evident in microwave flares only in 1978–1982, while Lean and Brueckner [1989] reported that during the period they considered (1954 to 1986), the 155-day periodicity was most evident in sunspot parameters in 1977 to 1984, again encompassing the maximum of cycle 21. Cane *et al.* [1998] concluded that the IMF showed a ~ 153 day period in 1978 to 1982, but this periodicity was absent around the maxima of the previous and subsequent solar cycles. Lean [1990] studied sunspot areas in cycles 12 – 21 (1891 – 1984) and concluded that the ~ 155 -day periodicity was present around each solar cycle maxima in episodes of 1 – 3 years duration. The exact period was found to vary from 130 to 185 days, and often to change significantly during a given episode of the “155-day” periodicity. Oliver and Ballester [1995] concluded however that the 155-day periodicity was absent in sunspot areas during the next cycle

(22). The origin of the 155-day periodicity is unclear, in particular whether it originates near the surface of the Sun [Bai, 1987, 1988; Wolff, 1983; Lou, 2000] or is a global phenomenon [e.g., Bai and Sturrock, 1987] possibly involving solar g-modes below the convection zone which couple with r-modes in the convection zone and give rise to the intermittency [Wolff, 1992]. The periodicity tends to be related to complex active regions containing large sunspots termed “superactive regions” [Bai, 1987; Lean, 1990].

In the present cycle (23), similar periodicities have been reported in solar energetic particle events (140 days) [Dalla *et al.*, 2001] and the occurrence rate of interplanetary coronal mass ejections (ICMEs; 166 days) [Cane and Richardson, 2003]; ICMEs are the manifestations in the solar wind of coronal mass ejections at the Sun. On the other hand, Özgüç *et al.* [2002] found no evidence of the 155-day periodicity in the flare index during cycle 23 up to the end of 2000. Given the reported association between the 155-day periodicity and major active regions in earlier solar cycles, we consider in this paper its possible relationship with the unexpected interval of intense solar activity in October – November 2003 during the late declining phase of cycle 23 and other intervals of enhanced activity during this cycle, focusing on the ICME rate, energetic particle events and sunspot numbers.

2. Observations

The top two panels of Figure 1 show 8-hour averages of the intensity of 24 – 28 MeV protons measured by the GME experiment on IMP 8, available to October, 2001 when data collection was terminated, and in a similar energy range (19 – 28 MeV) observed by the EPACT instrument on the WIND spacecraft. WIND data from January, 2000 to June, 2004 are shown, and proton enhancements associated with WIND crossings of the geomagnetic tail have been removed. The third panel shows the occurrence rate of ICMEs (/Car-rington rotation) in the near-Earth solar wind during 1996 – June, 2004, updated from the results reported by Cane and Richardson [2003]. Cane and Richardson [2003] noted that a Lomb frequency analysis [Lomb, 1976] of the ICME rate for 1996 – 2002 gave a significant peak at 166 days, the only such peak in the 50 to 300 day range. The extended data shown in Figure 1 give the same result. The dashed vertical lines are drawn at intervals of 166 days relative to November 1, 2003. Variations in the ICME rate with approximately this period (~ 6 solar rotations) are clearly evident through much of the interval in Figure 1 (for example, the dashed lines tend to align with temporary minima in the ICME rate), consistent with the frequency analysis. The fourth panel shows the monthly number of geomagnetic storm sudden commencements (data from the National Geophysical Data Center). SSCs are usually associated with the Earth passage of interplanetary shocks driven by ICMEs although may occasionally be related to corotating shocks. As might be expected given the close association with ICMEs, the SSC rate also shows evidence of periodic variations similar to those in the ICME rate. Lomb analysis of the SSC rate

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for 1998 to 2002 indicates prominent components at 131, 152 and 204 days.

The ICME and SSC rate enhancements typically correspond to intervals of temporarily enhanced solar activity, as indicated by the energetic ion enhancements in the top two panels and by variations in the monthly sunspot number (panel 5), the sunspot areas (values for the northern and southern solar hemispheres are shown in panels 6 and 7; the data are compiled by D. Hathaway), and the occurrence of M-class X-ray flares (/day) shown in panel 8. We also anticipate that the CME rate observed by the LASCO coronagraphs will show evidence of a ~ 155 -day periodicity given the close association between CMEs and ICMEs, SSCs, and major energetic proton events.

By late 2003, the ICME rate had fallen to $\sim 1 - 2$ /rotation, returning to approximately the level of early-mid 1997. The elevated ICME rate associated with the intense October - November, 2003 activity may be identified, but this was lower than was typical of episodes of enhanced activity earlier in the cycle. The October - November, 2003 activity is also clearly evident in for example the energetic particle intensity, the M-flare rate, and the daily sunspot number (bottom panel).

3. Does the October - November 2003 activity follow the " ~ 155 day" periodicity?

We consider first the energetic proton intensity in Figure 1. The proton data suggest that prior to the October - November, 2003 activity, two previous brief periods of activity indicated by energetic particle events in May - June, 2003 (also evident in the M-class flare rate) and November, 2002, denoted by arrows at the top of Figure 1 approximately followed the 166-day recurrence pattern indicated by the vertical dashed lines. This suggests that the October - November 2003 activity may have followed this periodicity. However, it is also evident that this pattern does not continue back in time into the earlier data around solar maximum. Here, if anything, the more prominent energetic particle events tend to cluster between the dashed lines, suggesting a phase shift relative to the periodicity in 2003. Additional evidence for this phase shift will be presented below. Then, in the early proton data (late 1997 - early 1999, and possibly extending back into 1996 during solar minimum conditions), the energetic particle events again typically cluster near the dashed lines. This is consistent with the periodicity in particle events during 1998 - 1999 noted by *Dalla et al.* [2001], although they estimate a slightly shorter period of ~ 140 days. Such differences in the periods inferred in different studies and data sets arise from factors such as the specific intervals of data considered and the quasi-periodic behavior of the phenomena under investigation.

We now consider variations in the ICME and SSC rates and their relation to the October - November, 2003 activity. As noted above, there was a local peak in the ICME rate at this time. As expected, one can also be identified in the SSC rate. There were slight increases in the ICME rate around the times of the solar particle events approximately one and two 166-day periods earlier discussed above, but more conspicuous peaks can be identified in the SSC rate. It is also evident that the ICME rate in 2002 and earlier tends to maximize *between* the vertical dashed lines, with minima tending to align with these lines. This indicates that enhanced ICME rate in October - November, 2003 was shifted in phase by \sim half a cycle relative to the periodicity in the ICME rate during much of the maximum of cycle 23, similar to the phase shift suggested by the energetic particle data as discussed above. Inspection of Figure 1 suggests that this phase shift most likely occurred late in 2002. The

SSC rate also shows evidence of this phase shift. Thus, although there is an indication that the October - November activity may have been related to the "155-day" periodicity, it was not simply a continuation of the periodic pattern of activity evident during the maximum of cycle 23, seen particularly clearly in the ICME rate, but also in the SSC rate and energetic particles. Rather, it occurred about a year after an apparent 180° phase shift in this pattern.

Variations in the monthly sunspot number also appear to be generally organized by a ~ 166 -day periodicity (a Lomb frequency analysis for the sunspot number in 1998 - 2002 indicates a ~ 137 -day component). Temporary enhancements in the sunspot number tend to be associated with enhancements in the ICME rate and energetic particles, though with occasional exceptions. The increase in sunspot number around the time of the October - November, 2003 activity followed the previous enhancement by $\sim 4 - 5$ months, which in turn essentially corresponds to the energetic particle activity in May - June 2003 noted above. There is no clear signature in the monthly sunspot number of the previous interval of particle activity in November 2002, but this may have been obscured by the general decline in sunspot number from ~ 110 to ~ 60 that was taking place at this time. It is interesting, though possibly coincidental, that this rapid decline in sunspot number occurred around the time of the $\sim 180^\circ$ phase shift inferred in the ~ 166 -day periodicity.

The variations in sunspot area follow a similar pattern to those in the sunspot number, and are typically more prominent in the northern hemisphere - Lomb analysis indicates a significant 176-day period, while the southern hemisphere has only multiple, weak components. This appears to continue the tendency for ~ 155 -day periodicities in sunspots to be more prominent in the northern hemisphere in cycles 15 - 21 noted by *Lean* [1990]. Nevertheless, the October - November, 2003 activity was prominent in both hemispheres. Furthermore, there is an indication from Figure 1 that the preceding two intervals of enhanced activity may have been more prominent in the southern hemisphere sunspots, suggesting that the phase shift in the ~ 166 -day periodicity in late 2002 may have been related to an increase in the contribution to the periodicity from the southern hemisphere.

If the ~ 166 -day pattern continued beyond October-November, 2003, enhanced activity might be expected around \sim April - May, 2004 and \sim October 2004. The top and bottom panels of Figure 1 do in fact suggest that there was a small resurgence of activity in April 2004, including an energetic particle event on April 11 and a brief increase in the sunspot number, that apparently conforms to the continuation of this pattern. However, it was clearly much less outstanding than that seen in October - November, 2003.

4. Summary and Discussion

A " ~ 155 -day" periodicity was first reported in many solar and interplanetary phenomena during cycle 21, and appears to have been intermittently present (with a period ranging from 130 to 185 days) during the solar maxima of cycles 12 - 21 *Lean* [1990], though cycle 22 may have been an exception [*Oliver and Ballester*, 1995]. Notwithstanding the conclusion of *Özgüç et al.* [2002], that the 155-day periodicity was also absent during cycle 23 based on the flare index up to the end of 2000, we suggest that it may have played a significant role in the ebbing and flowing of solar activity during this cycle. This is manifested particularly clearly

in the ICME rate inferred from near-Earth solar wind observations, which indicates a slightly longer period of 166 days.

A relationship between the October – November, 2003 activity and the “155-day” (or rather 166-day) periodicity is suggested by intervals of increased activity preceding the October – November activity by around one and two times this period, separated by quieter intervals. A interval of slightly enhanced activity in April, 2004 may have been a continuation of this pattern. However, these intervals of activity were $\sim 180^\circ$ out of phase relative to the earlier \sim periodic activity variations closer to solar maximum, the phase change occurring around late 2002.

As has been suggested previously [e.g., Bai 1989], identifying such periodicities in solar and interplanetary phenomena when they exist, and understanding their origin, may provide a tool for flare prediction on timescales of several months, although the uncertainty in the exact period, which may change significantly during a given episode of the “155-day” periodicity [Lean, 1990] and knowledge of when the periodicity will be present are important limitations. In the present cycle, simply extrapolating the pattern of activity evident through solar maximum into the declining phase would not have predicted the October – November, 2003 activity because of the phase shift in late 2002. On the other hand, if the continuing pattern after the phase shift had been recognized, then an increase in activity in October – November, 2003, but certainly not its unusual intensity, might have been anticipated. We also note that in cycle 21, the “155-day” pattern appears to have ordered much of the activity during much of the cycle including the declining phase with little evidence of a similar phase shift (e.g., Figure 1 of Cane *et al.* [1998]). Thus, recognition of, and identification of the 155-day periodicity in solar activity, if present, may be a useful, but certainly not infallible, key to the prediction of future major activity.

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Figure 1. Overview of solar and interplanetary phenomena in 1996 – May, 2004 and their relationship to the 166-day periodicity inferred from the ICME rate in panel 2, (dashed lines) drawn relative to November 1, 2003. From top: IMP 8 24 – 28 MeV and WIND 19 – 28 MeV proton intensities (8-hour averages), rate of ICMEs/solar rotation (updated from Cane and Richardson [2003]; number of SSCs/month; the monthly sunspot number, sunspot areas (millionths of hemisphere) in the northern and southern hemisphere (compiled by D. Hathaway), and the daily rate of M-class X-ray flares.

